



Standardization of Fertigation Rate and Scheduling in Tomato (*Solanum lycopersicum* L.) under Open Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. Author TGT conducted the study and wrote the first draft of the manuscript. Authors RLRR and KP designed the study, wrote the protocol, guided the study and done statistical analysis. Author BND managed the analysis and provided technical advices during the study. Author KP managed the literature searches. All authors read and approved the final manuscript.

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Abstract

Background: Optimising fertigation rate and nutrient scheduling is important for tomato production under open-field conditions.

Aim: To optimise the fertigation rate and scheduling of water-soluble fertilisers for tomato under open conditions.

Study Design: Factorial RCBD.

Place and Duration of Study: RHREC, UHS Campus, GKVK, Bengaluru, Karnataka, during rabi 2025–26.

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Methodology: The experiment comprised ten treatments and three replications: nine combinations of three fertiliser levels (125, 100, and 75% RDF) and three fertigation schedules, and conventional soil application of RDF as the control. Growth parameters, including plant height, number of branches, and flowering time, as well as yield parameters, including fruit number and yield, were recorded.

Results: Among the fertiliser levels, 100 % RDF recorded the significantly highest fruit yield (77.91 t ha⁻¹), whereas 75 % RDF resulted in the highest number of fruits per plant (66.17). Among the fertigation schedules, S₃ recorded superior performance for all yield attributes and produced the significantly highest yield (88.39 t ha⁻¹). Among the treatment combinations, T₉ (75% RDF + S₃) recorded the significantly highest fruit yield (90.83 t ha⁻¹) whereas T₆ (100% RDF + S₃) recorded the maximum average fruit weight (91.83 g).

Conclusion: The 75% and 100% RDF levels produced comparable results for several parameters, while schedule S₃ outperformed the other schedules. Thus, 75% RDF applied through S₃ was identified as an effective fertigation strategy under the experimental conditions.

Keywords: Tomato, fertigation rate; drip irrigation, recommended fertiliser dose; water-soluble fertilisers; nutrient management; fruit yield.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop grown extensively across different parts of the world. Its wide adaptability, economic value, and nutritional importance have contributed to its extensive cultivation under diverse agro-climatic conditions. Its ability to perform under varied soil and climatic conditions has made it an important component of vegetable production in tropical as well as temperate regions.

Despite its high production potential, the average productivity of tomato in India is lower than that in many developed countries. This gap is attributed to several constraints, including imbalanced fertiliser application, inefficient irrigation practices, poor nutrient management, soil fertility degradation, water scarcity, climate variability and increasing production costs. Among these factors, improper management of irrigation water and plant nutrients remains one of the major limitations affecting tomato productivity and fruit quality. Since tomato has a shallow, actively growing root system with high nutrient requirements throughout its growth cycle, a continuous and balanced supply of nutrients as well as water is essential for achieving higher yields and better fruit quality (Hartz and Hanson, 2009). A recent open-field tomato study assessed the combined effects of drip irrigation and nitrogen application rates on yield, reinforcing the relevance of examining water and nutrient management together (Bello *et al.*, 2024).

Conventional methods of fertiliser application generally involve broadcasting or basal placement of fertilisers, which often result in poor synchronisation between nutrient availability and crop demand. Similarly, surface irrigation methods frequently apply water in excess of crop requirements, resulting in nutrient losses, poor aeration, uneven moisture distribution and reduced crop performance (Kuscu *et al.*, 2014). In a tomato study conducted under protected cultivation, Singh *et al.* (2024) compared different irrigation and nutrient application regimes, further indicating that fertiliser delivery should be considered alongside irrigation management.

Drip irrigation has emerged as a better alternative because it delivers water directly to the crop root zone with minimal conveyance and evaporation losses. Fertigation ensures uniform nutrient distribution in the wetted root zone, improves nutrient availability, enhances fertiliser use efficiency and minimises nutrient losses by leaching and volatilization (Kafkafi and Tarchitzky, 2011). In addition, fertigation promotes vigorous root development, improves nutrient uptake, enhances photosynthetic activity and ultimately increases crop performance while reducing labour requirements and production costs (Hartz and Hanson, 2009). In solar-greenhouse tomato production, the effects of soil-moisture-responsive fertigation schedules on irrigation water and nutrient use efficiency have also been investigated (Wang *et al.*, 2024).

The success of fertigation, however, largely depends on the fertiliser dose, timing, frequency and scheduling of nutrient application. Excessive nutrient application causes increased production costs, nutrient imbalance, salt accumulation in soil and environmental contamination. Conversely, inadequate fertiliser supply may restrict plant performance and limit yield potential. Therefore, nutrients should be supplied in accordance with crop demand at different phenological stages to maximise nutrient uptake and fertiliser use efficiency. Crop stage-specific fertigation schedules have been shown to enhance nutrient absorption, fruit quality and water productivity by minimizing fertiliser losses (Kuscu *et al.*, 2014; Selvaganapathi *et al.*, 2024). Related research in bhendi (okra) has evaluated reduced nitrogen application rates under drip fertigation; however, findings from that crop cannot be directly assumed to apply to tomato (Vijayakumar *et al.*, 2025).

Although previous investigations have considered fertigation rates and nutrient schedules, their combined effects under the open-field conditions of the present experiment require direct assessment. Comparing different proportions of the recommended fertiliser dose and growth-stage-specific schedules with conventional soil application may help identify a suitable fertigation strategy for the conditions studied.

Keeping these aspects in view, the investigation entitled "Standardization of fertigation schedule in tomato under open field conditions" was conducted with the objective of optimising the fertigation rate and scheduling of water-soluble fertilisers for tomato.

2. Materials and Methods

A field experiment was conducted at the RHREC, UHS Campus, GKVK, Bengaluru, Karnataka, which lies at 13.09° N latitude and 77.56° E longitude, falling under the Eastern Dry Zone of Karnataka (Zone-5). The soil at the experimental site was sandy loam in texture, neutral in reaction (pH: 6.78), low in total soluble salts content (EC: 0.11 dS/m) and had a medium organic carbon content

(0.5%). The soil had low available nitrogen (250.87 kg/ha), medium available P₂O₅ (41.15 kg/ha) and high available K₂O (373.14 kg/ha). The experiment was laid out in a factorial randomised block design comprising ten treatments and three replications. Of the ten treatments, nine were combinations of two factors, while the tenth involved soil application of RDF (250:250:250 kg NPK/ha) designated as the control. The two factors were fertiliser levels, namely F₁, F₂, and F₃, corresponding to 125 %, 100 %, and 75 % RDF, respectively, and three fertigation schedules (Table 1). The variety selected for the study was Arka Rakshak, which was planted at a spacing of 120 cm × 45 cm with an individual plot size of 3.6 m × 4.5 m. Growth parameters such as plant height, number of branches, days to first flowering and 50 % flowering, and yield parameters such as the number of fruits per cluster and per plant, average fruit weight, and yield per plant, plot, and hectare were recorded manually and statistically analysed using ANOVA. The methods used to determine soil chemical properties are presented in Table 2 (Subbiah & Asija, 1956).

Table 1. Fertigation schedules designed for the experiment

Growth stage (Days)	No. of splits	Nutrients applied			Source / Type of fertilizer
		N	P2O5	K2O	
Schedule 1 (S ₁)					
10-25 DAT	4	10% of total N	10% of total P2O5	10% of total K2O	19:19:19
26-55 DAT	4	40% of total N	40% of total P2O5	40% of total K2O	12:61:00, 13:00:45, CN
56-85 DAT	4	30% of total N	25% of total P2O5	30% of total K2O	00:52:34, 13:00:45, CN
86-120 DAT	4	20% of total N	25% of total P2O5	20% of total K2O	19:19:19, H3PO4
Schedule 2 (S ₂)					
10-25 DAT	4	25% of total N	25% of total P2O5	25% of total K2O	19:19:19
26-55 DAT	4	25% of total N	25% of total P2O5	25% of total K2O	12:61:00, 13:00:45, CN
56- 85 DAT	4	25% of total N	25% of total P2O5	25% of total K2O	00:52:34, 13:00:45, CN
86-120 DAT	4	25% of total N	25% of total P2O5	25% of total K2O	19:19:19
Schedule 3 (S ₃)					
10-25 DAT	4	20% of total N	20% of total P2O5	20% of total K2O	19:19:19
26-55 DAT	4	30% of total N	30% of total P2O5	30% of total K2O	12:61:00, 13:00:45, CN
56- 85 DAT	4	30% of total N	30% of total P2O5	30% of total K2O	00:52:34, 13:00:45, CN
86-120 DAT	4	20% of total N	20% of total P2O5	20% of total K2O	19:19:19

* DAT: Days after transplanting, CN: Calcium nitrate

Table 2. Methodologies followed the determining the chemical properties of the experimental soil

Particulars	Methodology
pH	Potentiometric method using digital pH meter, Jackson, 1973
Electrical conductivity (EC)	Conductimetric method using conductivity meter, Jackson, 1973
Organic carbon	Wet oxidation method, Walkley and Black, 1934
Available Nitrogen	Alkaline potassium permanganate method, Subbaiah and Asija, 1956
Available P ₂ O ₅	Bray's /Olsen's extraction and Colorimetric estimation, Jackson, 1973
Available K ₂ O	NN NH ₄ OAC extraction and Flame photometric estimation, Jackson, 1973

3. Results and Discussion

3.1 Growth

3.1.1 Fertigation Rates

Table 3 indicates that plant height and the number of branches were significantly influenced by fertiliser doses at 50 and 75 DAT but not at 25 DAT. F₁ registered the maximum height of 96.60 cm and 84.85 cm at 75 and 50 DAT, respectively while F₃ recorded the lowest plant height at the respective intervals. The superior growth under F₁ may be attributed to greater nutrient availability, particularly nitrogen, which promotes cell division, elongation and vegetative development. An improvement in plant height and branch number with increased fertiliser supply through fertigation was also reported (Brahma *et al.*, 2010).

Regarding the days to first flowering, F₂ (21.11 days) recorded earlier flowering but was on par with F₃ (21.33 days) while F₃ resulted in earlier 50 % flowering (25.33 days).

3.1.2 Schedules

The various schedules showed no significant variation in plant height but showed a significant difference in the number of branches at 50 and 75 DAT (Table 3). S₃ recorded the maximum number of branches at both intervals (10.15 and 13.47, respectively) while S₁ recorded the fewest branches at all the intervals. The greater branching under S₃ may be attributed to the more efficient and timely supply of nutrients and water, which enhanced vegetative growth and promoted lateral shoot development (Brahma *et al.*, 2010). Similarly, S₃ resulted in significantly fewer days to first flowering and 50 % flowering (21.11 and 25.22 days, respectively).

The earlier flowering under F₂, F₃ and S₃ may be attributed to a balanced nutrient supply that favoured the timely transition from vegetative to reproductive growth, whereas higher nutrient availability may have prolonged vegetative development (Prabhakar *et al.*, 2012).

3.1.3 Interaction

No significant differences were recorded at all three intervals in plant height and the number of branches among the treatments (Table 3). However, the control treatment recorded the maximum plant height and number of branches at 25 DAT while fertigation treatments significantly outperformed the control at 75 DAT. This may be attributed to the continuous and efficient supply of water and nutrients through fertigation, which supported sustained vegetative development during the later growth stages. However, the control treatment recorded significantly earlier first flowering and 50% flowering (18.67 and 22.00 days, respectively). In the control treatment, 50 % N and the full doses of P and K were applied as a basal dose 25 days before planting, while fertigation treatments began 5 days after transplanting, which may have contributed to the delay in flowering under fertigation.

Table 3. Tomato growth as influenced by fertigation rates and scheduling

Treatments	Plant height (cm)			No of Branches			Days to	
	25	50	75	25	50	75	1 st flower	50% flower
Days after transplanting (DAT)								
F ₁	48.80	84.85	96.60	5.26	10.32	12.87	23.22	27.44
F ₂	48.17	81.50	93.69	5.43	9.72	12.73	21.11	25.56
F ₃	48.26	78.68	88.24	5.22	9.39	11.64	21.33	25.33
SE(m) ±	0.72	1.28	1.36	0.06	0.13	0.16	0.29	0.32
C.D. @ 5%	NS	3.87	4.11	NS	0.40	0.49	0.89	0.97
S ₁	48.70	80.76	90.40	5.19	9.43	11.49	22.67	26.78
S ₂	47.48	80.76	92.84	5.30	9.85	12.29	21.89	26.33
S ₃	49.04	83.52	95.29	5.43	10.15	13.47	21.11	25.22
SE(m) ±	0.72	1.28	1.36	0.06	0.13	0.16	0.29	0.32
C.D. @ 5%	NS	NS	NS	NS	0.40	0.49	0.89	0.97
T ₁ (F ₁ S ₁)	48.83	83.89	97.13	5.11	9.06	11.13	21.00	25.00
T ₂ (F ₁ S ₂)	48.50	85.94	99.27	5.22	9.00	11.27	22.67	26.67
T ₃ (F ₁ S ₃)	49.06	84.72	93.40	5.44	10.11	12.53	20.33	24.33
T ₄ (F ₂ S ₁)	48.72	84.22	96.87	5.34	9.28	11.53	22.33	26.33
T ₅ (F ₂ S ₂)	46.67	80.17	92.27	5.33	9.94	12.87	20.67	25.67
T ₆ (F ₂ S ₃)	49.11	80.11	91.93	5.61	9.95	13.80	20.33	24.67
T ₇ (F ₃ S ₁)	49.56	82.44	91.87	5.11	9.95	11.80	24.67	29.00
T ₈ (F ₃ S ₂)	47.28	76.17	87.00	5.33	10.61	12.73	22.33	26.67
T ₉ (F ₃ S ₃)	47.94	77.44	85.87	5.22	10.39	14.07	22.67	26.67
SE(m) ±	1.25	2.22	2.35	0.11	0.23	0.28	0.51	0.55
C.D. @ 5%	NS	NS	NS	NS	NS	NS	1.54	1.67
T ₁₀ (Control)	49.83	77.44	83.00	5.72	9.56	11.27	18.67	22.00
SE(m) ±	1.19	2.22	2.92	0.10	0.26	0.27	0.49	0.53
C.D. @ 5%	NS	NS	8.75	0.31	0.78	0.81	1.48	1.57

* F₁ – 125 % RDF, F₂ – 100 % RDF, F₃ – 75 % RDF and S₁, S₂, S₃ - different ratios of N, P and K given at different growth stages of tomato crop

3.2 Yield

3.2.1 Fertigation Rates

Table 4 shows that 100 % RDF produced a higher number of fruits per cluster, significantly higher yields per plant, plot, and hectare, and a higher average fruit weight than 125 and 75 % RDF. The superior performance of 100 per cent RDF may be attributed to adequate and balanced nutrient availability throughout the crop period, which supported fruit setting, fruit development and assimilate translocation. Optimum fertigation improves tomato yield through the adequate and efficient availability of nutrients (Ankush *et al.*, 2017). By contrast, 75 % RDF resulted in an earlier fruit harvest and a higher number of fruits per plant, indicating that efficient delivery of nutrients through drip fertigation could satisfy crop requirements even at a reduced fertiliser level.

3.2.2 Schedules

The S₃ schedule significantly outperformed the other schedules in all yield-related parameters (Table 4). The better performance of S₃ schedule may be because S₃ supplied a larger proportion of nutrients during 26–85 DAT, resulting in improved synchronisation of nutrient availability with crop demand. Frequent and timely nutrient application through drip irrigation using optimised fertigation schedules can maintain a favourable nutrient concentration in the root zone, improve nutrient uptake and have a positive influence on yield characteristics in tomato. (Selvaganapathi *et al.*, 2024).

3.2.3 Interaction

Regarding the number of fruits per cluster, no significant difference was found among factorial treatments although T₆ recorded a significantly higher number of fruits per cluster (7.83) than the control (6.17) (Table 4). The higher fruit number under T₆ may be attributed to the combined effect of adequate nutrient availability and an efficient fertigation schedule, which ensures a continuous nutrient supply and may support improved pollen viability, reduced flower drop, and enhanced fruit retention (Dorais *et al.*, 2000).

T₃ recorded the highest number of fruits per plant (71.57), which was statistically on a par with T₈ (71.39), T₉ (70.93), T₅ (70.81) and T₆ (69.47) while T₄ recorded the lowest number of fruits per plant (55.74). The higher number of fruits under these treatments may be attributed to improved nutrient availability during the reproductive phase through an optimised fertigation schedule, resulting in better fruit set and retention because it ensures a continuous supply of nutrients during reproductive growth (Ughade *et al.*, 2015; Selvaganapathi *et al.*, 2024).

T₆ recorded the highest average fruit weight (91.83 g), which was on a par with T₉ (89.95 g). This may be attributed to better nutrient availability during fruit development, particularly improved assimilate production and translocation towards developing fruits. The lowest fruit weight was recorded in T₁ (68.83 g), while the control T₁₀ recorded 74.22 g, indicating comparatively better fruit development under the fertigation treatments, as balanced nutrient management during fruit bulking is essential for maximising fruit size and marketable yield (Hartz & Hanson, 2009).

Regarding yield, T₉ recorded significantly higher yields per plant, plot, and hectare, with a total yield of 90.83 t ha⁻¹ but was on a par with T₆ (90.44 t ha⁻¹). The lowest yield was recorded in T₇ and T₁ (57.94 and 58.76 t ha⁻¹, respectively) while the control recorded a yield of 70.67 t ha⁻¹. The superior yield under T₉ and T₆ may be attributed to the efficient synchronisation of nutrient supply with crop demand under S₃, resulting in better fruit production and development. The comparable performance of T₉ with T₆ indicates that 75 per cent RDF, when supplied through an efficient fertigation schedule, achieved a yield comparable to that obtained with 100 per cent RDF (Hebbbar, 2004).

Table 4. Effect of different fertigation rates and scheduling on yield and yield related parameters

Treatments	No of fruits / cluster	No of fruits / plant	Avg. fruit weight (g)	Yield / plant (kg)	Yield / plot (kg)	Yield / ha (tonne)
F ₁	6.57	66.04	77.52	5.15	138.86	72.75
F ₂	7.07	65.34	83.78	5.50	148.46	77.91
F ₃	6.94	66.17	82.72	5.29	142.99	75.02
SE(m) ±	0.18	0.43	0.35	0.01	0.27	0.18
C.D. @ 5%	NS	NS	1.07	0.03	0.80	0.55
S ₁	6.22	57.42	74.37	4.18	112.90	59.25
S ₂	6.93	69.47	81.48	5.52	148.98	78.05
S ₃	7.44	70.66	88.17	6.24	168.44	88.39
SE(m) ±	0.18	0.43	0.35	0.01	0.27	0.18
C.D. @ 5%	0.53	1.41	1.07	0.03	0.80	0.55
T ₁ (F ₁ S ₁)	6.22	60.33	68.83	4.15	111.96	58.76
T ₂ (F ₁ S ₂)	6.61	66.21	81.00	5.36	144.71	75.60
T ₃ (F ₁ S ₃)	6.89	71.57	82.72	5.92	159.90	83.90
T ₄ (F ₂ S ₁)	6.28	55.74	77.45	4.32	116.34	61.05
T ₅ (F ₂ S ₂)	7.11	70.81	82.05	5.81	156.75	82.25
T ₆ (F ₂ S ₃)	7.83	69.47	91.83	6.38	172.31	90.44
T ₇ (F ₃ S ₁)	6.17	56.19	76.83	4.32	110.40	57.94
T ₈ (F ₃ S ₂)	7.06	71.39	81.39	5.81	145.47	76.30
T ₉ (F ₃ S ₃)	7.61	70.93	89.95	6.38	173.10	90.83
SE(m) ±	0.31	0.74	0.61	0.02	0.46	0.32
C.D. @ 5%	NS	2.45	1.86	0.06	1.39	0.95
T ₁₀ (Control)	6.17	67.23	74.22	4.99	134.71	70.67
SE(m) ±	0.33	0.71	0.58	0.02	0.44	0.32
C.D. @ 5%	0.99	2.31	1.74	0.06	1.31	0.96

* F₁ – 125 % RDF, F₂ – 100 % RDF, F₃ – 75 % RDF and S₁, S₂, S₃ - different ratios of N, P and K given at different growth stages of tomato crop

4. Conclusion

From the overall results of the present investigation, it can be concluded that the application of 75 per cent of the recommended dose of water-soluble fertilisers in combination with fertigation schedule S₃ proved to be the most effective treatment for better yield and productivity of tomato under open-field conditions. Among the different fertiliser doses, F₃ consistently recorded superior performance for most of the yield parameters. Likewise, among the fertigation schedules, S₃ produced significantly higher yield and better nutrient use efficiency owing to timely and uniform nutrient application through the drip system. The fertigation treatments also performed better than the conventional soil application of fertilisers (control) by improving nutrient availability, nutrient uptake and crop productivity.

5. Limitations

This experiment was conducted during a single rabi season at one site using the Arka Rakshak cultivar; its findings cannot be generalised to other seasons, cultivars, soils or climatic conditions without additional trials. The reported measurements focused on growth, flowering and yield. Direct assessments of nutrient uptake, fertiliser-use efficiency, water productivity, fruit quality, economic returns and long-term soil responses were not presented.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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